15. I have sought for interference effects of the X-rays, but possibly, in con-

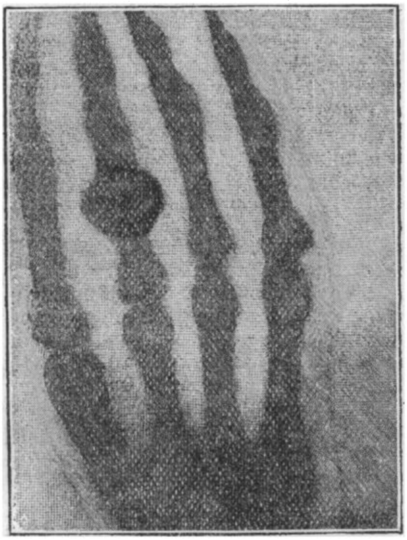

FIG. 1.—Photograph of the bones in the fingers of a living human hand. The third finger has a ring upon it.

sequence of their small intensity, without result.

16. Researches to investigate whether electrostatic forces act on the X-rays are begun, but not yet concluded.

17. If one asks, what then are these X-rays; since they are not cathode rays, one might suppose, from their power of exciting flourescence and chemical action, them to be due to ultra-violet light. In opposition to this view a weighty set of considerations presents itself. If X-rays be indeed ultra-violet light, then that light must possess the folling properties.

(*a*) It is not refracted in passing from air into water, carbon bisulphide, aluminium, rock salt, glass or zinc.

(*b*) It is incapable of regular reflection at the surfaces of the above bodies.

(*c*) It cannot be polarized by any ordinary polarizing media.

(*d*) The absorption by various bodies must depend chiefly on their density.

That is to say, these ultra-violet rays must behave quite differently from the visible, infra-red, and hitherto known ultra-violet rays.

These things appear so unlikely that I have sought for another hypothesis.

A kind of relationship between the new rays and light rays appears to exist; at least the formation of shadows, fluorescence, and the production of chemical action point in this direction. Now it has been known for a long time that, besides the transverse vibrations which account for the phenomena of light, it is possible that longitudinal vibrations should exist in the ether, and according to the view of some physicists must exist. It is granted that their existence has not yet been made clear, and their properties are not experimentally demonstrated. Should not the new rays be ascribed to longitudinal waves in the ether?

I must confess that I have in the course of this research made myself more and more familiar with this thought, and venture to put the opinion forward, while I am quite conscious that the hypothesis advanced still requires a more solid foundation. W. C. RÖNTGEN.

RÖNTGEN RAYS.

PROFESSOR RÖNTGEN'S discovery brings to a close a most interesting chapter in the history of electricity; it is the chapter dealing with electric discharges through rarefied gases. Experiments on electric discharges through vacua have for quite a long period now attracted the attention of physicists. Elaborate accounts of these experiments can be found in the transactions of learned societies throughout the last century. A systematic research into the various phenomena accompanying vacuum discharges dates from the time of Faraday. Plücker, Hittorf and Goldstein in Germany, and Spottiswoode and Crookes in England, may be mentioned as the foremost

investigators who extended very much what Faraday had only commenced. Among the numerous, most interesting, and indeed remarkable, results obtained by these investigators, the behavior of the discharge, which under certain conditions, emanates from the negative electrode, the so-called cathode, was always considered as the most remarkable.

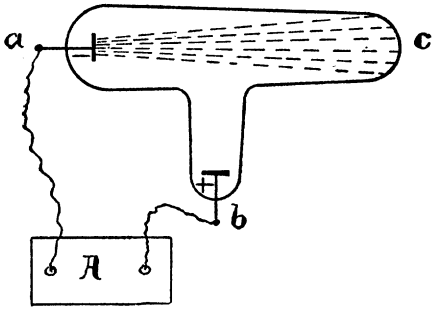

Fig. I. represents a typical form of the vacuum tube capable of showing a strongly developed cathode discharge. At *a* we have one electrode and at *b* the other. They consist of platinum discs attached to platinum wires which are sealed in the glass. Let the electrode *a* be connected to the negative, *b* to the positive pole of the induction coil A. As the air pressure in the tube is reduced, the color and the general appearance of the discharge continually changes character. When the pressure reaches a small fraction of a millimeter of mercury the intensity of the discharge in the gas itself becomes very much reduced, but in its place appears a strong fluorescence of the glass. This fluorescence is produced by faint streamers which proceed in straight lines from the negative electrode, as indicated by the straight lines in Fig. I., from the disc at *a* toward the terminal *c* of the tube. These streamers are called the cathode rays. Professor Crookes, of London, advanced the theory that the streamers represent a fourth state of matter, which he called radiant matter. According to this theory there is matter moving from the negative electrode, where it is projected by the action of electric force, and whenever this moving matter strikes the glass it causes it to fluoresce. A radiometer interposed properly in the path of the streamers will be set into rotation. The fact that the fluorescing portions of the tube become very hot when the action of the coil is powerful seemed to support Crookes' hypothesis, namely, that there is along the path of the cathode rays projected matter moving with very high velocity.

Other theories concerning these rays were proposed, but none of them are entirely free from serious objections. Röntgen's discovery will probably enable us to decide very soon which among the several existing theories is the correct one. The theory which probably has the most followers on the continent will be mentioned presently.

Cathode rays are deflected by magnetic force; the direction of the deflection is roughly stated the same as if each ray were a flexible conductor carrying a current with one of its terminals attached to the cathode. The late Professor H. Hertz discovered in 1891 that cathode rays are capable of passing through thin sheets of metal like gold leaf, aluminum, silver, etc., if these sheets are placed within the vacuum in the path of the rays. Dr. Lenard, an adjunct to Hertz, extended this discovery two years ago by showing that the cathode rays can be made to pass out of the vacuum tube into the external space, if the tube is provided with a small window of thin aluminum. But as soon as they pass into the external atmosphere they are rapidly absorbed; this absorption results in a flourescence of the gas. Various gases possess various degrees of this absorptive power and the absorption in a given layer of gas is proportional to its density. Solid bodies absorb them very much more strongly on account of the

greater density. The resulting flourescence in gases seems to indicate that the cathode rays in passing through a gas undergo a diffuse reflection resembling the reflection in a turbid medium, just as if the molecules of the gas were very large in comparison to the wave-length of these rays. That the radiance which produces the fluorescence is really a continuation of the cathode rays is demonstrated by the fact that it is deflected by magnetic force.

Röntgen's discovery adds a new accompaniment to the cathode rays. It shows that, in addition to the heat and flourescent light which the cathode rays generate in the glass of the vacuum tube wherever they strike it, there is also another form of radiant energy generated there. Röntgen calls it the X-rays. The rays will and should, of course, be called the Röntgen rays. They are not cathode rays, according to the reports which have reached us so far; for although they are capable of producing strong flourescence, just like the cathode rays, they are not acted upon by magnetic force, and not only are they not absorbed by gases at ordinary pressure, but even the most opaque of all substances, that is the metals, are more or less transparent with respect to these new rays. Cardboard, wood, ebonite, organic substances, etc., are about as transparent to them as glass is to the visible part of the spectrum. They are neither reflected nor refracted, that is not to any appreciable degree. They act upon a photographic plate, but it is evident that photography by means of these rays cannot employ lenses and that the pictures obtained will be shadow pictures. The object to be photographed is placed between the plate and the vacuum tube. It is to to be hoped that these shadow pictures of the interior of living organisms will soon be perfected so as to show us the various parts in various shades according to the absorptive power of each part.

The question arises, what is this new form of radiant energy? The report says that the discoverer has expressed, but with much reserve, his belief that it is a longitudinal vibration of the ether. If so, then its velocity of propagation will in all probability be much larger than that of light, and therefore for the same period of vibration as that of visible light these new rays may have a very much larger wave-length. Should this belief of the discoverer prove correct, then we shall finally have the longitudinal wave in the ether for which we have looked so long, in order to avoid the necessity of considering the ether an incompressible solid elastic. It is well to mention here that quite a large number of very distinguished German physicists have within the last few years advocated quite strongly the theory that cathode rays are longitudinal vibrations of the ether. Prof. Jaumann, of Vienna, has published quite recently a very elaborate mathematical formulation of this theory. It is an application of Maxwell's electro-magnetic theory to a mediun whose specific inductive capacity and permeability vary under the action of electric force. Such a medium is in all probability a gas in a state of high tenuity, as for instance in a Crookes' tube. This theory will not account satisfactorily the longitudinal character of the Röntgen rays.

The correct view of this new radiant energy will undoubtly soon be formed when new experimental data appear. In the meantime we can rest assured that a new entrance to the region of the ether phenomena has been opened, and the importance of this fact can hardly be overestimated.

After the above note had been written the author succeeded in repeating some of Prof. Röntgen's experiments. The tubes employed were of an inferior quality on account of the poor vacuum. The poorer the

vacuum the longer must be the time of exposure under otherwise identical conditions. The tubes were used as electrodeless tubes, that is, a tinfoil strip was wrapped around each end of the tube, and then the tinfoils were connected to a high tension coil with disruptive spark gap and Leyden jar. The vacuum discharge is, of course, in such cases due to the condenser effect. The writer's experiments lead to the conclusion that quite as powerful effects can be produced in this manner as with electrodes, and it obviates the risk of spoiling the tube by excessive heating of the platinum wires carrying the electrode discs. It is well to observe here that with electrodeless tubes the glass under the tinfoil becomes very hot indeed in quite a short time, when powerful, rapid electric oscillations are employed. But on account of the large tinfoil surface which is in contact with the outside air the temperature of the tube never becomes dangerously high. Some of the results of the writer's experiments seem to be of sufficient interest to deserve a brief mention here.

An under-exposed plate fails completely to bring out the relative absorption of the materials placed in the path of the rays. For instance, the photograph of a cigar box made of aluminium sheet about $\frac{1}{16}$ of an inch thick and containing several opaque objects will show no detail if the exposure is too short. All that we see is the contour of the box, and the area bounded by this contour is uniformly illuminated. With a sufficiently long exposure the contour is still strong, but the area enclosed by the contour is scarcely visible and the objects in the box appear in sharp outline. Various objects were photographed and the results were similar to those obtained by Professors Trowbridge and Wright. The most interesting photograph obtained was that of a pair of spectacles in a leather case (see Plate III., Fig. 1). It bears upon the subject mentioned in the last paragraph. The exposure lasted an hour; the tube had the highest vacuum among the several tubes employed. In all previous photographs the lenses of these spectacles appeared as perfectly flat discs of high opacity. In this photograph, however, obtained with long exposure, the varying thickness of the lens is beautifully marked in the negative. The central part of the lens is darkest, and then the increase in luminosity toward the edge was gradual, showing distinctly the curvature of the lens. This photograph seems to support the writer's belief that the relative amounts of absorption in the various parts of the object photographed are brought out in a photographic plate if it is exposed a sufficiently long time, but not otherwise. In the photography of the human hand, for instance, there is no trace of the skeleton unless the exposure is sufficiently long. The contour surrounding the uniformly illuminated surface of the hand is very easily obtained with a short exposure. But to obtain an image of the skeleton of the hand the exposure must be sufficiently long, and it appears that the longer the exposure the stronger is the impression of the contour of the bones and the weaker is that of the surrounding flesh.

Prof. Röntgen's photograph of the human hand is the only one in which the flesh is almost entirely invisible. In Mr. Swinton's photograph the fleshy part of the hand is nearly as strongly marked out as the bony part. The writer cannot agree with Mr. Swinton's opinion that this is due to overexposure, and prefers to consider the presence of the fleshy part of the hand as due to underexposure. At any rate, the difference between the Röntgen photograph of the human hand and the photographs obtained by other experimentalists, including the writer, seems to deserve further investigation. A fluorescent screen placed in front of the sensitive plate for the purpose of

Fig. 1. Leather case containing eye-glasses. Cigar case of aluminium $\frac{1}{16}$ inch thick, containing scissors, knife, etc. Exposure 1 hour (M. I. PUPIN).

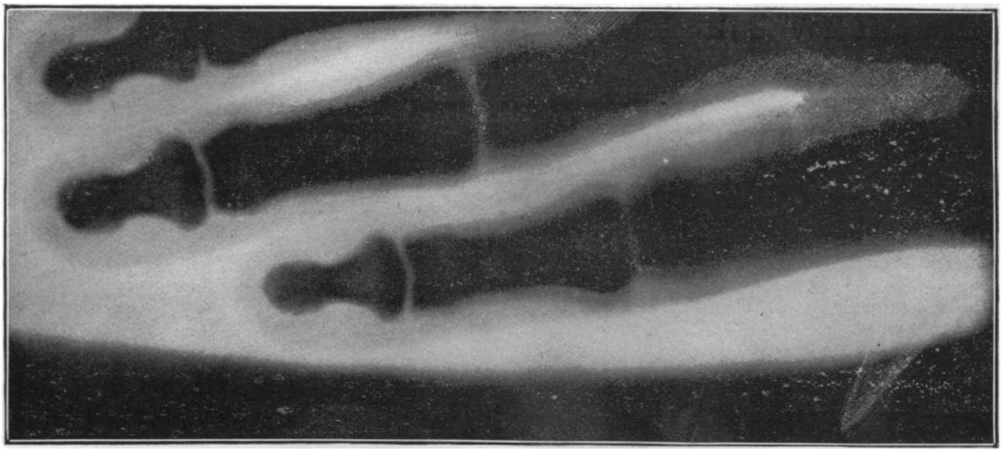

Fig. 2. Fingers taken with exposure of 20 minutes (E. B. FROST).

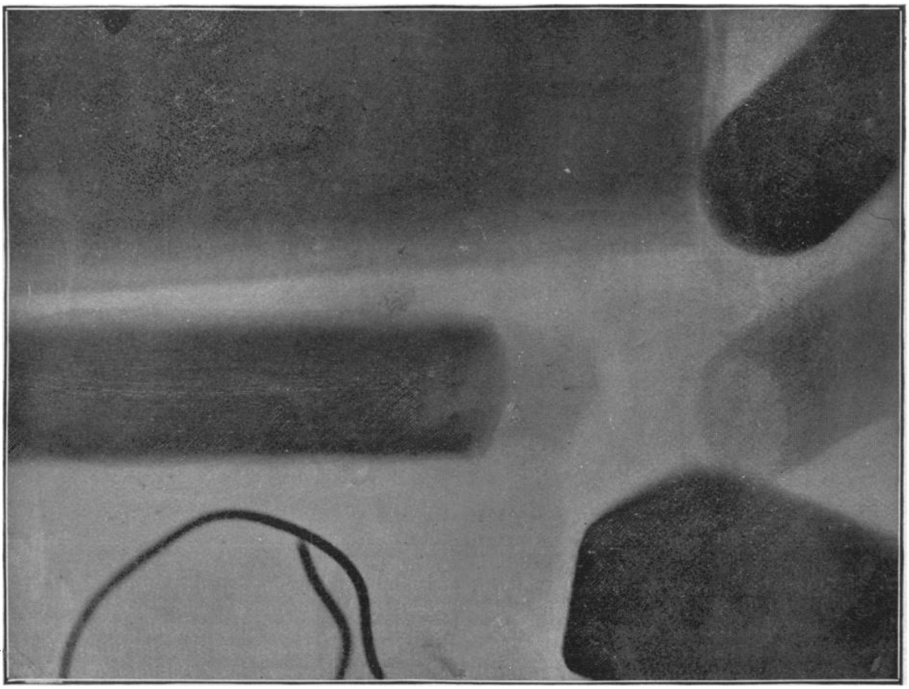

Fig. 1. The varying transparencies of a number of substances for the X-rays. At the top is a book; to its right a 'rubber' cork about 2 cm. high; just below that a 'cork' cork of equal thickness, but of far greater transparency; in the right lower corner is a crystal of Iceland spar, 1 cm. thick; in the left lower corner a loop of aluminium wire enclosing little Canada balsam (shows faintly); between the loop of wire and the spar may be very faintly seen a very thin piece of mica; above this is a hard rubber tube containing water with cork stopper; the superior transparency of cork to that of water is well shown where the cork is pressed into the rubber tube. (E. B. FROST.)

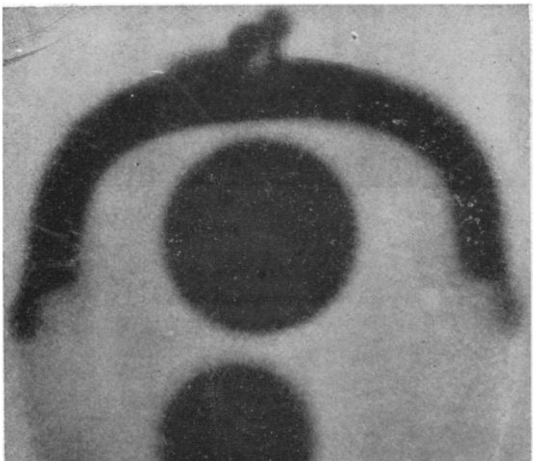

Fig 2. Coins in leather purse (A. W. GOODSPEED).

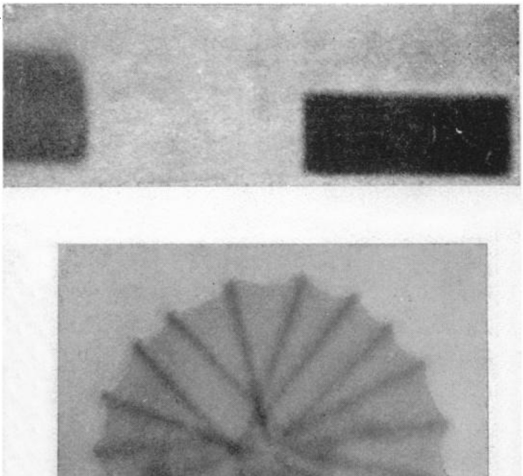

Fig. 3. Pins in cushion (A. W. GOODSPEED).

shortening the time of exposure gave encouraging results. A shortening of the time of exposure and the simplification of the apparatus employed is very desirable in the practical application of this wonderful discovery. The prospects are that both will soon be reached. It should be mentioned in this connection that a Whimshurst or a Holtz machine can very well be employed in place of the somewhat complicated apparatus employed so far. These machines should be used to charge a small Leyden jar and discharge it between small spheres which are at a suitable distance from each other. The tinfoil coatings of the vacuum tube should then be connected suitably to the coatings of the jar. This arrangement is much simpler than the one usually employed and will in all probability give just as good results—perhaps even better, because a disruptive character of the discharges seems to improve the results. This method, however, is offered as a suggestion only, since the writer could not procure a statical machine in time to convince himself of the actual value of the suggested arrangement. The practical applicability of this method of photography to surgery seems certain.

M. I. PUPIN.

COLUMBIA COLLEGE, February 8, 1896.

EXPERIMENTS ON THE X-RAYS.

EXPERIMENTS with Röntgen's newly detected X-rays have been carried on during the past few days in the Dartmouth physical laboratory by Prof. C. F. Emerson and the writer, and some of the preliminary results already obtained may be worth recording.

Of four Crookes tubes first tried, but one emitted rays which (with the exposure given) made a visible impression upon a photographic plate protected from the ordinary luminous rays. This tube is 4.7 cm. in diameter and is cylindrical for a length of 16 cm., then tapering to a point. The platinum electrodes are on opposite sides of the cylindrical surface and are about 5 cm. apart. A phosphorescent plate is interposed obliquely between the electrodes. In action the phosphorescent surface is bombarded by the discharge from the negative pole. We have thus far usually excited the tube by a current from an efficient induction coil, but a Holtz machine has served about equally well.

The first successful experiment gave, after 12 minutes of exposure, a picture of a knife and scissors hung on the side (1 cm. thick) of a whitewood box, within which the photographic plate had been placed.

Subsequently, the Crookes tube was supported horizontally, and the plate-holder could then be laid upon the table and any object interposed that was desired. No camera was employed, and the slide of the plate holder was not drawn, so that no exposure to the ordinary luminous rays could occur.

A coin and key concealed between two boards of total thickness, 24 mm., were shown after an exposure of 11 minutes, the tube being 15 cm. above the plate. The power of transmitting the X-rays has been tested for a number of substances. Silver and gold seem to be the most opaque of the metals yet tried, although aluminium transmits poorly. Glass is more opaque than brass, and less so than hard rubber. Cork transmits better than any other substance examined. (See Plate 4, Fig. 1.)

An attempt to refract the rays by a carbon disulphide prism was unsuccessful, and they seemed to pass through a pair of crossed tourmalines without difficulty. No effect except that of the usual metallic obstruction was noted when the wire conveying the primary current was passed over the plate, or when the alternate current of the house circuit was sent through a loop of insulated wire resting on the plate holder.

With the tube 9 cm. above the plate an exposure of 15 minutes clearly brought out